APPARATUS AND METHOD FOR CALIBRATING A LASER IMAGIBLE APPARATUS

BACKGROUND

[0001] As a laser (or other light source) and sensing lens are moved radially (by an optical pick-up unit ("OPU")) with respect to a disc in a disc drive, the distance between the surface of the disc and the lens (hereinafter referred to as a Z-distance) is substantially constant. However, various imperfections may arise over the surface of the disc and/or the shape of the disc may vary. For example, the disc may be subject to "potato chipping" (i.e., where the disc bends along a diameter) or "cupping" (i.e., where the outer edge of the disc are generally planar but not coplanar with the center of the disc). Previous methods and apparatuses have addressed these imperfections such that the lens remains substantially at a Z-distance of optimum focus with respect to each portion of the disc. The Z-distance of optimum focus will correspond to the Z-distance at which a maximum amount of data can be written to a disc or read from it. There may, however, be other applications in which the Z-distance of optimum focus may not be ideal. Accordingly, there is a need to know the gain corresponding to optimum focus at each location on a disc.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] Figure 1A is a graph of a voice coil applied voltage defined by a changing coil voltage (mV) versus time (ms);

[0003] Figure 1B is graph of the lens Z-distance corresponding to the voice coil applied voltage of Figure 1A showing the distance (μm) the lens moves versus time (ms);

[0004] Figure 2A is a graph of a voice coil slew rate ρ of the type shown in Figure 1A;

[0005] Figure 2B is a first sum signal ρ_1 which corresponds to the voice coil slew rate ρ of Figure 2A;

[0006] Figure 2C is a second sum signal ρ_2 which corresponds to the voice coil slew rate ρ of Figure 2A;

[0007] Figure 2D is a third sum signal ρ_3 which corresponds to the voice coil slew rate ρ of Figure 2A;

[0008] Figure 3 is a graph of the peak of the second sum signal ρ_1 of Figure 2B;

[0009] Figure 4 is a schematic diagram of an embodiment of a method of calibrating the Z-distance of a lens, the method may be performed by a program product embodiment; and

[0010] Figure 5 is a schematic depiction of an embodiment of a CD drive comprising a disc tray, a lens, and an adjustment mechanism configured to adjust a Z-distance between a disc provided in the disc tray and the lens.

DETAILED DESCRIPTION

[0011] Reference will now be made in detail to various embodiments of the invention, which are illustrated in the drawings. An effort has been made to use the same reference numbers throughout the drawings to refer to the same or like parts.

[0012] Typically, a lens is positioned at a Z-distance corresponding to a height at which the disc is in optimum focus. An understanding of the orientation of the Z axis along which the Z-distance offset is adjusted is provided in Figure 5B. The Z-distance of optimum focus may be determined based on a peak in a sum signal returned to the lens, as later described in detail. However, when creating a label designed for readability by the human eye, a Z-distance other than optimum focus may be desired, i.e., defocusing the laser beam may allow better image quality and/or faster printing.

[0013] The chemistry used in CD label laser imaging can only handle a maximum light intensity and must be kept above a critical temperature for a period of time. With a laser beam at optimum focus, increasing the laser power allows the print time to speed-up to a point at which the media is damaged by the laser. One solution is to increase the laser power and defocus the beam

using a Z-distance offset, so that the system can write a larger spot at one time and, thereby, print faster. For example, the ability to write to a disc may be enhanced when the Z-distance of the lens is slightly offset (e.g., 30μm) from the Z-distance of optimum focus.

[0014] An optimum focus is conventionally defined by an OPU forming the smallest diameter spot on the disk as defined by the spot's full width half maximum ("FWHM"). If 0μm corresponds to the Z-distance of the lens at optimum focus, a light intensity best for labeling could correspond to an offset between about -80μm (i.e., toward the disc) and about +20μm (i.e., away from the disc). In one embodiment, the offset may be about -30μm, i.e., in the middle of this range. Accordingly, if the Z-distance of optimum labeling focus is about 1.4mm, the Z-distance of focus offset for labeling would be about 1.4mm - 30μm = about 1370μm from the disc.

[0015] To achieve this -30μm offset, the voltage applied to the voice coil (which would otherwise maintain the lens at a predetermined Z-distance, such as the Z-distance of optimum focus) must be changed. The degree to which the voltage must be changed, in turn, depends on the coil gain ("CG") of the voice coil of the CD drive. The coil gain controls the Z-distance of a lens with respect to a disc. With respect to Figures 1A and 1B, the voice coil gain for a given change in time Δt (ms), is defined is a change in voltage ΔV (mV) needed to move the lens a certain distance ΔZ (μm), as follows:

$$CG = \Delta Z / \Delta V \qquad \text{eq. 1}$$

[0016] When the voltage or current (hereinafter simply referred to as "voltage") supplied to the voice coil is changed, the Z-distance of the lens is correspondingly changed. For example, as shown in Figures 1A and 1B, when the voltage supplied to the voice coil increases, the Z-distance of the lens correspondingly increases, usually with a phase shift delay caused by mechanical inertia. However, the change in Z-distance ΔZ for a particular change in voltage ΔV is not readily measurable in conventional optical drives and, therefore, the coil gain can not simply be calculated based on measured change in Z-distance ΔZ and a measured change in voltage ΔV.

[0017] However, from equation no. 1, if the coil gain can be determined, a change in voltage ΔV can be calculated to correspond to a desired change in Z-distance ΔZ as follows:

$$\Delta V = \Delta Z / CG \qquad \text{eq. 2}$$

[0018] Another complication arises in that the coil gain is subject to change over the surface of the disc. For example, coil gain is most strongly affected by temperature changes as the printing process progresses. Accordingly, although a predetermined offset could be applied to the lens in a conventional CD drive, the result would not be effective due to the varying coil gain. As a result, if the offset is to be effective, the coil gain must be continually evaluated and adjusted in an iterative manner at each location on the disc, so that the correct voltage offset may be applied to obtain the desired Z-distance offset. As a result, an accurate understanding of the coil gain at each location on the disc is needed to set the correct Z-distance offset ΔZ at each location on the disc.

[0019] As shown in Figures 2A-2D, as the coil voltage increases linearly over time (as shown in Figure 2A) at a constant voice coil slew rate ρ, the Z-distance of optimum focus is identified by the peak in the sum signal (as shown in Figures 2B-2D) at a time t_1. However, for a given scan time, the shape of the peak in the sum signal ρ_1, ρ_2, ρ_3, may vary (as shown) depending on the age of the voice coil motor, sample intervals, the direction of sample (i.e., as the lens moves toward or away from the disc), media type changes in operating temperatures, or other reasons. For this reason, voice coil gain calculations based on the peaks in the sum signal ρ_1, ρ_2, ρ_3, may be averaged, filtered, regressed, etc. to obtain a more accurate coil gain. Moreover, many samples (e.g., 100+) and associated calculations may be averaged, filtered, regressed, etc. to obtain a more accurate coil gain.

[0020] It has been determined that the coil gain at a particular location on a disk is related to the sum signal at that location and the input voice coil slew rate. Specifically, the rate of change of voltage in the sum signal in the vicinity of the optimum focus peak for a particular location on a disc defines a sum signal slew

rate at that location. The sum signal slew rate can be calculated with the known input voice coil slew rate to yield the coil gain, as hereafter described in detail.

[0021] The controlled change in the coil voltage defines an input voice coil slew rate ("VCSR"). Specifically, with respect to Figure 2A, the VCSR is defined as:

$$VCSR = \Delta V_C / \Delta t_C = (V_{C2} - V_{C1}) / (t_{C2} - t_{C1}) \qquad \text{eq. 3}$$

[0022] As shown in Figure 3 (which is an enlarged view of the sum signal ρ_1 of Figure 2B in the vicinity of the point of optimum focus), a rise time Δt_R (or fall time Δt_F) of the peak can be measured with respect to the change in sum voltage ΔVs_R (ΔVs_F for t_F) which occurs during that time.

[0023] For accuracy purposes, it is preferred that a rise time Δt_R (or fall time Δt_F) and associated voltage change ΔVs_R (ΔVs_F for Δt_F) are measured between the points in time at which the peak has reached 40% of its peak value and 90% of its peak value, when measured from a baseline value (as shown). The reason for this range limitation is that below 40%, the sum signal is subject to double reflection and above 90% the sum signal is subject to noise which may occur when the surface of the disc approaches optimum focus. Further, although the measurement times are shown as being taken at 40% and 90%, it should be understood that the measurement times may be made anywhere between 40% and 90%. Moreover, as later described, measurements may be taken during both the rise time Δt_R (i.e., between 40% and 90%) and the fall time Δt_F (i.e., between 90% and 40%) and these measurements may be averaged, filtered, regressed, etc. to yield a more accurate result.

[0024] As shown in Figure 3, a rise time Δt_R may be measured between a time t_{R1} at which the peak hits its 40% value and a time t_{R2} at which it hits its 90% value. Similarly, a fall time Δt_F may be measured between a time t_{F1} at which the peak hits its 90% value and a time t_{F2} at which it hits its 40% value. As a result:

$$\Delta t_R = t_{R2} - t_{R1} \qquad \text{eq. 4}$$

$$\Delta t_F = t_{F2} - t_{F1} \qquad \text{eq. 5}$$

[0025] The change in the rise time sum voltage ΔVs_R associated with the rise time Δt_R is calculated by subtracting the sum voltage at t_{R1} from the sum voltage

at t_{R2}. Similarly, the change in the fall time sum voltage ΔVs_F associated with the fall time Δt_F is calculated by subtracting the sum voltage at t_{F2} from the sum voltage at t_{F1}.

[0026] It should be noted that if the same peak percentage points are used on both the rise and fall of the peak, the change in rise time sum voltage ΔVs_R is the same as the change in fall time sum voltage ΔVs_F and can simply be defined as ΔVs (as shown). It should be understood, however, that if different peak percentage points are used, the change in rise time sum voltage ΔVs_R and fall time sum voltage ΔVs_F may differ.

[0027] The sum signal slew rate SSR for the rise time Δt_R and fall time Δt_F may be defined as follows:

$$SSR_1 = \Delta t_R / \Delta Vs_R \qquad \text{eq. 6}$$

$$SSR_2 = \Delta t_F / \Delta Vs_F \qquad \text{eq. 7}$$

[0028] Either of these sum signal slew rates can be used to calculate the coil gain as later described in detail. However, the sum signal slew rates SSR_1, SSR_2 may be averaged, filtered, regressed, etc. For example, the sum signal slew rates SSR_1, SSR_2 may be averaged to obtain a more accurate sum slew rate ("SSR") as follows:

$$SSR = (SSR_1 + SSR_2) / 2 \qquad \text{eq. 8}$$

[0029] Moreover, as the shape of the sum signal may vary, as previously discussed, it is also possible to obtain more than one sum signal and perform SSR determinations for each of these additional sum signals. In addition, as there may be a lag between the voice coil slew rate and the sum signal, error may be introduced in measuring the sum signal slew rate. This error, however, may be substantially negated by passing the point of optimum focus twice, i.e., once in the positive Z direction and once in the negative Z direction.

[0030] The coil gain can be calculated using the input voice coil slew rate previously discussed with respect to equation no. 3. As a result of knowing both the sum signal slew rate and the voice coil slew rate, the coil gain may be calculated using a constant k associated with the OPU used to move the lens. The coil gain may be calculated as follows:

$$CG = (k)(1000\mu m/mm)(SSR) / (VCSR) \qquad \text{eq. 9}$$

[0031] For example, if an NEC 9100A optical pick-up unit having constant k of 2.54E-3 mm/V were used and the sum signal slew rate were calculated to be 2V/18.67ms and if the input voice coil slew rate were 0.619mV/ms, the coil gain would be:

$$CG = (2.54E\text{-}3mm/V)(1000\mu m/mm)(\ 2V/18.67ms)/(\ 0.619mV/ms) \qquad \text{eq. 10}$$

$$CG = 0.440\mu m\ /mV \qquad \text{eq. 11}$$

[0032] Therefore, according to equation 2, the coil voltage offset ΔV_{OS} would be determined from the Z-distance offset Z_{OS} and the coil gain as follows:

$$\Delta V_{OS} = (Z_{OS}) / CG \qquad \text{eq. 12}$$

[0033] If a Z-distance offset Z_{OS} of -30μm were desired, the coil voltage offset ΔV_{OS} would be decreased as follows:

$$\Delta V_{OS} = -30\mu m / (0.440\mu m\ /mV) = -68.18mV \qquad \text{eq. 13}$$

[0034] As a result, if the voltage V_{OF} applied to the coil at the point of optimum focus were 1.0V, the voltage V_{OS} applied at the offset Z-distance would be:

$$V_{OS} = V_{OF} - \Delta V_{OS} = 1.0V - 68.18mV = 931.82mV \qquad \text{eq. 14}$$

[0035] In practice, the coil gain should be determined as printing progresses across the disc and the input voice coil voltage should be adjusted accordingly. Further, to enhance accuracy, multiple coil gain determinations may be made at each location the disc; the various coil gain results may be averaged, filtered, regressed, etc.

[0036] With respect to Figure 4, a series of steps can be described as follows to calculate of the voice coil gain and the change in voltage offset ΔV_{OS} needed to move a lens to a predetermined Z-distance offset Z_{OS}. These steps, of course, would substantially be performed after the laser power is decreased so as to prevent marking on the disc.

[0037] In a first step 110, a desired Z-distance offset Z_{OS} is predetermined. For example, if the initial Z-distance of the lens is defined as 0μm, a Z-distance offset may be defined, for example, between about -80μm (i.e., toward the disc) and about +20μm (i.e., away from the disc). In step 120, which may be either after step 110 or simultaneous therewith, a substantially fixed voice coil slew

rate is applied to the lens 230 (shown in Figure 5A) to move the lens 230 through vertical range which includes a Z-distance of optimum focus Z_{OF}. As the voice coil slew rate is applied to the lens, the sum signal versus time reflected by the disc to the sensor is monitored, as shown in step 130. Upon obtaining the sum signal, the peak corresponding to the Z-distance of optimum focus Z_{OF} is identified in step 140. From the rise time and/or fall time of the peak in the sum signal, the sum signal slew rate may be calculated in step 150. In step 160, upon calculating the sum signal slew rate, the voice coil gain may be calculated using the input voice coil slew rate and the calculated sum signal slew rate. Once the voice coil gain is determined, the voice coil gain may be used along with the desired Z-distance offset Z_{OS}, to calculate the coil voltage offset ΔV_{OS}, in step 170. Finally, in step 180, the coil voltage offset ΔV_{OS} may be applied to the coil voltage at optimum focus V_{OF} to yield an offset coil voltage V_{OS}.

[0038] It should, of course, be understand that as this method may entail an iterative process for each location on a disc. As a result, upon setting the offset coil voltage V_{OS} for a particular location on the disc, the process may be repeated (starting either at step 110 or at step 120) with another location on the disc.

[0039] The aforementioned method may be comprised in a program product embodiment which, in turn, may be comprised in a CD drive, a DVD drive, or other optical (or non-optical) drive embodiment. For example, a microcontroller (which may be an adjustment mechanism 240, as shown in Figure 5A), comprising a programmed product, may control the radial and/or Z-distance movements of the lens 230 with respect to the disc 220. In addition, the microcontroller program product may also control the coil gain and/or Z-distance offset calculations (including averages, regressions, etc.) at each location on the disc as well as the number of samples from which these calculations are derived. In other words, a microcontroller may comprise a program product configured to perform the aforementioned Z-distance calibration method steps.

[0040] Figure 5 is a schematic depiction of a CD drive, other optical drive, or similar laser imagible device (hereinafter "CD drive") 200 which is configured to perform the calibration method previously described. The drive 200 includes a tray 210 which is configured to hold a disc or other media (hereinafter "disc") 220. Light is emitted by a light source 250 (e.g., a laser diode) and reflects off the disc 220 and into the objective lens 230, as hereafter explained in detail.

[0041] For the lens 230 to focus the reflected light properly, the lens 230 must be properly spaced from the disc 220 by a proper Z-distance. The Z-distance, which is the space between the lens 230 and the disc 220, is adjusted according to the method previously described by controlling the voltage on the movable coils 236. The movable coils 236 move the lens 230 toward and away from the disk based on the voltage induced therein by stationary magnets 238.

[0042] With respect to Figure 5, the light source 250 emits light as indicated by the directional arrows emanating therefrom. The light passes through a collimating lens 232 and through a diffraction grating 280. After passing through the diffraction grating 280, the light passes through a beam splitter 270 and then through a quarter wave plate 234; the quarter wave plate 234 changes the polarization of the light from linear to circular. After passing through the quarter wave plate 234, the light enters and passes through the objective lens 230.

[0043] The objective lens 230 focuses the light on a spot on the disc 220 which, in turn, reflects the light (as shown) back through the objective lens 230. The reflected light then passes back through the quarter wave plate 234 which reverts the light back to a linear polarization. After passing back through the quarter wave plate 234, the light is redirected by the beam splitter 270 toward a second lens 239 which focuses the light into a sensor 300. The sensor 300 generates the sum signal waveform previously discussed.

[0044] As a result of the sum signal, the coil gain can be determined according to the previously discussed method. In turn, the coil gain may be used with the Z-distance offset Z_{OS}, to calculate the coil voltage offset ΔV_{OS}. An adjustment mechanism 240 may then adjust the magnets 238 so that the voltages induced in the coils 236 will be adjusted by the calculated coil voltage offset ΔV_{OS}. As a

result of the change in voltage induced in the coils 236, the objective lens 230 will move a distance (with respect to the disc 220) substantially equal to the Z-distance offset Z_{OS}.

[0045] In addition to performing the aforementioned coil gain calibrations, the adjustment mechanism 240 may adjust the Z-distance so that the lens is in substantially optimum focus or at a predetermined offset from optimum focus. Moreover, these calibrations may be performed at each location on the disc. For example, the adjustment mechanism 240 could adjust the Z-distance such that the lens 230 were between about -80μm toward the disc and about +20μm away from the disc, assuming 0μm were the Z-distance corresponding to optimum focus. More specifically, the adjustment mechanism 240 could adjust the Z-distance such that the lens 230 were at about -30μm.

[0046] Although the aforementioned describes embodiments of the invention, the invention is not so restricted. It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed embodiments of the present invention without departing from the scope or spirit of the invention. Accordingly, these other voice coil gain calibration systems and methods of adjusting the input voice coil voltage to attain a predetermined Z-distance offset are fully within the scope of the claimed invention. Therefore, it should be understood that the apparatus and method embodiments described herein are illustrative only and are not limiting upon the scope of the invention, which is indicated by the following claims.